RESTORATION OF LOSS OF BONE

INCLUDING AN ANALYSIS OF THE FIRST HUNDRED CASES OF FRACTURE TREATED BY BONE GRAFT AT U. S. ARMY GENERAL HOSPITAL NO. 3, COLONIA, N. J.*

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In the task of restoring loss of bone substance and function in the wide variety of traumatisms resulting from the war, the plastic surgeon is confronted with a correspondingly varied array of mechanical problems. The recognition of the underlying biologic and physiologic significance of tissue growth and metabolism is a fundamental requirement in the successful treatment of these cases. The surgical repair of bone, and more particularly the use of the bone graft in cases of pseudarthrosis with or without bone loss, is based not only on the ultimate establishment of adequate fixation of the bone fragments, but also on the attainment of a proper environment for the nourishment of the graft. This entails the exact coaptation of parts of the graft to respective parts of the host bone; in other words, the adequate and extensive contact of all four corresponding bone layers, namely, periosteum, cortex, endosteum and marrow.

MECHANICAL STRESS AND BONE GROWTH

Throughout his plastic work, both in civilian practice and army experience, the author has been greatly impressed with the striking influence exerted by mechanical stress on the growth and metabolism of bone. In cases of loss of substance of long duration, in the radius, humerus or any long bone, the bone cortex has often become reduced to one-fifth its normal thickness, in fact, almost to eggshell consistency, largely owing to removal of the stimulus of mechanical stress. Such a condition is, of course, in direct sequence to the general physiologic law of bone growth; it is, in fact,

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a magnification of Wolff's law. If bone, whose nourishment and blood supply have not been greatly impaired, should suffer so materially as a result of loss of the stimulus of mechanical stress, how much greater must be the effect of the same inhibitory influences on any free bone graft whose blood supply and nourishment are not yet established.

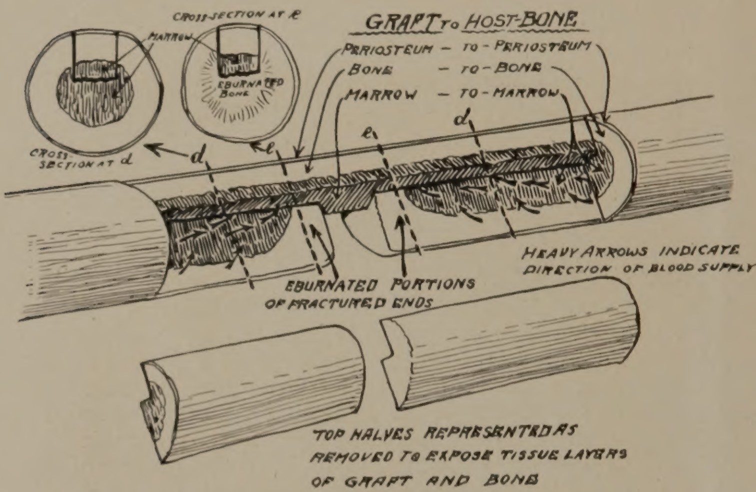

Fig. 1.—Requisite apposition of bone layers of graft with respective parts of host bone. The graft is of sufficient length to extend well beyond the eburnated area of the host fragments, coming into generous contact with the healthy vascular marrow substance. The cross-section at *E* shows the eburnated plug of bone where, as a rule in pseudarthrosis, it closes the marrow cavity in the fractured ends. Here the gutter has been deepened sufficiently to receive the full amount of marrow of the graft, which is demonstrated (lower drawing and cross-section at *D*) in extensive contact with the marrow of the host fragments. The arrows on the marrow in the host fragments indicate the direction of blood supply to the graft from its principal normal source, namely, the marrow substance of the host. By the insertion of the inlay, with its full amount of marrow, a continuous marrow bridge is formed, extending from the healthy marrow of both host fragments through the gutter in the eburnated ends. This marrow bridge plays a most important rôle as conductor of blood vessels and osteogenic cells from one host fragment to the other. The cross-sections at *D* and *E* show also the cabinet-maker fit of the inlay graft with the host fragments, which not only affords mechanical fixation of parts, but also favors the stimulus to bone growth from frictional irritation, emphasized by Roux.

A more suitable environment for successful bone growth is established by the cabinet-maker fit of the properly inserted inlay graft than by any other known technic. At the same time the biologic laws that obtain in the transplantation of all varieties of tissues are fulfilled, since corresponding tissue-layers

are brought in apposition, thereby furnishing ideal conditions for the rapid and complete establishment of the blood supply. Under such conditions, Wolff's law of bone growth is given favorable opportunity to exert its influence on bone proliferation and on the adequate adjustment of the bone architecture. Moreover, by the inlay technic, the full influence of Roux's

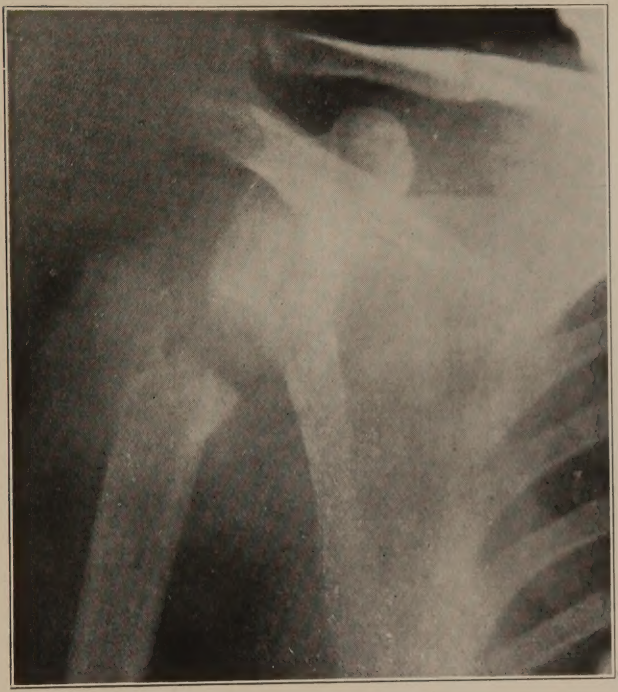

Fig. 2 (Case 1).—Wound in which an officer, hit at Ourcq River by fragments of a high explosive shell, lost about 3½ inches of the upper third of the humerus, including the entire head. In this case, destruction of practically all the musculature of the shoulder rendered the patient incapable of shoulder motion.

law of frictional irritation is ideally provided for, since extensive plane surfaces of the graft are brought into the closest proximity with equally extensive plane surfaces of the host fragments.

TECHNIC

In work on bone tissues, which easily dry on exposure to the air, operative speed is necessary; moreover, in the repair of bone that from lack of the stimulus afforded by mechanical stress has become almost eggshell-like in consistency, great delicacy of technic and operative speed are fundamental requirements in the difficult work of inserting the necessary inlay. It would be impossible to execute such accurate inlay technic by the former laborious methods with mallet and chisel, or osteotome. In work of this nature, in which the operating field is frequently lim-

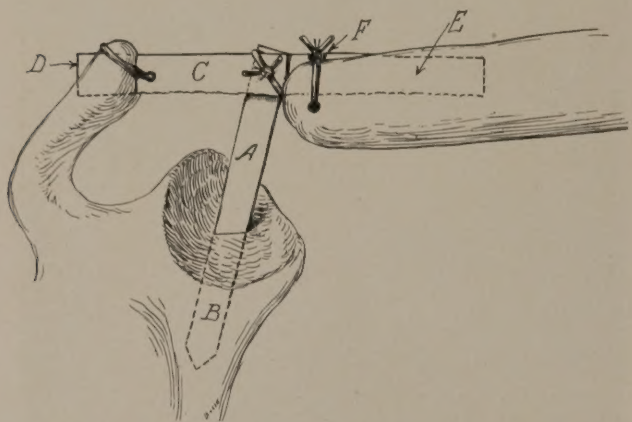

Fig. 3 (Case 1).—Diagrammatic drawing (anterior view) to show the trusswork of tibial grafts in position and fixed with kangaroo tendon. Graft *C* is inlaid into the shaft of the humeral fragment at *E*, and mortised into the acromion process at *D*. Graft *A* is mortised into the glenoid body of the scapula at *B*, and attached by means of kangaroo tendon to Graft *C* at the point where the latter graft meets the end of the humeral fragment.

ited, where fragility of bone may be a constant menace to success, and in which an accurate cabinet-maker fit of parts is indispensable, an electrically driven rotary twin-saw seems absolutely essential. In contradiction to a recent assertion, it is emphatically stated that the motor-saw, when properly used, does not heat nor glaze the bone. During various operations in the past few months, the author has made repeated attempts to determine whether heat was generated by the motor-saw when used properly, and if so, to what degree. In every instance it has been found that the most delicately

adjusted thermometers have failed to register an increase in temperature, even to the fraction of a degree, when placed directly on the motor-saw or on the bone immediately following the withdrawal of the instrument.

Fig. 4 (Case 1).—The plastic operation in this case was performed four and one-half months after the patient was wounded and two months after the wound had healed. The roentgenogram demonstrates restoration of loss of bone by two tibial grafts, eight weeks after operation. Graft 1 was inlaid into the shaft of the humerus and mortised into the acromion process. Graft 2 was mortised into the glenoid body of the scapula and contacted with Graft 1 at the point where that graft met the humerus. During the union of the grafts the arm was held by a plaster-of-Paris shoulder spica in an elevated anterior posture and in such relation to the scapula that the powerful thoracic muscles controlling this bone might later move it and in a large measure restore its loss of function by causing the scapulothoracic motion to be compensatory for loss of shoulder motion.

Methods of Internal Fixation.—For the inlay graft, accurately cut and fitted by motor-saw technic, the fixation afforded by kangaroo sutures is adequate and preferable to that of all metal agents (such as plates,

nails, screws or wire). Kangaroo tendon, from the standpoint of mechanical strength, absorbability and tolerance by the tissues, surpasses all known fixation agents. It remains in situ sufficiently long for the purpose of fixation, and begins to be absorbed within forty days. Moreover, it is sufficiently elastic to allow the plane surfaces of an inlay graft to rub in a microscopic amount on the contiguous plane surfaces of the gutter of the host fragments, thus favoring the frictional irritation law of Roux.

The practice of inserting metal plates (as recommended by some surgeons) is absolutely contraindicated in this work. The use of metal plates as the internal fixation agent not only robs the graft of mechanical stress, but an influence is thereby added that contributes strongly toward the stirring up of old infections, if such remain in the tissues. Whereas, in tissues retaining only a slight amount of an original infection, a bone-graft operation speedily done with minimum trauma may bring satisfactory results, the introduction of a foreign body (such as a metal plate, nails or screws) adds a second devitalizing element, which, in the battle of tissues, may turn the scales unfavorably, with the result that infection again breaks out.

ANALYSIS OF CASES

A careful analysis of the first 100 cases of fracture treated by bone graft at U. S. Army General Hospital No. 3 during the period from July 15, 1918, to May 1, 1919, has yielded, it is believed, valuable data in regard to possibilities of treatment.

Of the 100 cases, seventy-nine involved bones in which injury resulted from high explosive shell, machine gun bullet, or shrapnel; seventeen were simple fractures of the long bones; the remaining four cases were compression fractures of the spinal vertebrae. All the simple fractures and the spine cases have been successfully treated, in that they have healed, in each instance, without infection, and have shown bone growth by roentgenographic examination within a reasonable period after transplantation of the graft. In every case of fracture of the long bones, function has been restored, while in the spine cases there has been an inhibition of symptoms.

Of the seventy-nine cases of fracture by projectiles, treated by bone graft, sixty-five, or 82 per cent., were for loss of substance varying in amount from one-half inch to six inches, and averaging about two inches; ten cases were for nonunion without loss of bone; the remaining four cases were for malunion. These cases are classified anatomically in Table 1.

TABLE 1.—SEVENTY-NINE CASES OF FRACTURE TREATED BY BONE GRAFT, GROUPED ACCORDING TO THE BONES INJURED

Site of Injury	No. of Cases
Radius	23
Ulna	17
Radius and ulna	4
Humerus	12
Humerus and ulna	2
Metacarpal	3
Mandible	1
Total cases, head and upper extremities	62
Tibia	12
Femur	4
Patella	1
Total cases, lower extremities	17
Total number of cases considered	79

SPECIAL METHODS

Some of the various methods of plastic repair employed in this series of fractures, more than four fifths of which involved loss of bone, are briefly described in the following groups of cases:

Restoration of Loss of Bone at Shoulder.—Owing to the exposure of the upper portion of the body in trench warfare, shoulder injuries, and particularly those involving the upper part of the humerus, have been frequent in the recent war. Through the rather extensive practice of certain surgeons at the front, more especially of the French, of removing large portions of bone at or near the shoulder-joint in such injuries as these, there has resulted a notable group of cases in which shoulder function is very nearly negligible, if not entirely destroyed, on account of the loss of bony framework over which the shoulder muscles might play. Of all surgical conditions, none presents a picture of greater helplessness than a dangling arm from which the upper portion of the humerus is missing.

The high frequency of shoulder and forearm injuries is strikingly borne out in Table 1. In this series of seventy-nine cases of fracture by war projectiles, injury to bones of the upper extremities, as compared with those of the lower, has occurred in a ratio of nearly 4 to 1. Of the total number of cases of injury in the upper extremity, the humerus has been involved in fourteen instances, or more than 25 per cent. Cases of loss of substance in the humerus with loss of shoulder function have been classified in two groups, with respect to treatment:

Fig. 5 (Case 1).—Type of brace applied after removal of the plaster spica. This brace is so adjusted as to allow the arm to descend to a lower position than that maintained during the union of the grafts to scapula and humerus. This new position brings a slight amount of lateral stress on the grafts, thus stimulating their hypertrophy and development. It is obvious that this new posture causes the lower angle of the scapula to separate itself from the thoracic cage.

Group 1. Restoration of Shoulder Motion and Function: This class consists of cases in which the humerus has been destroyed, but the musculature has been sufficiently preserved to enable the surgeon to hope for a return of shoulder-joint motion and function, provided the bone be replaced. The author has restored motion and function in such cases by transplanting into the humeral fragment the head and upper

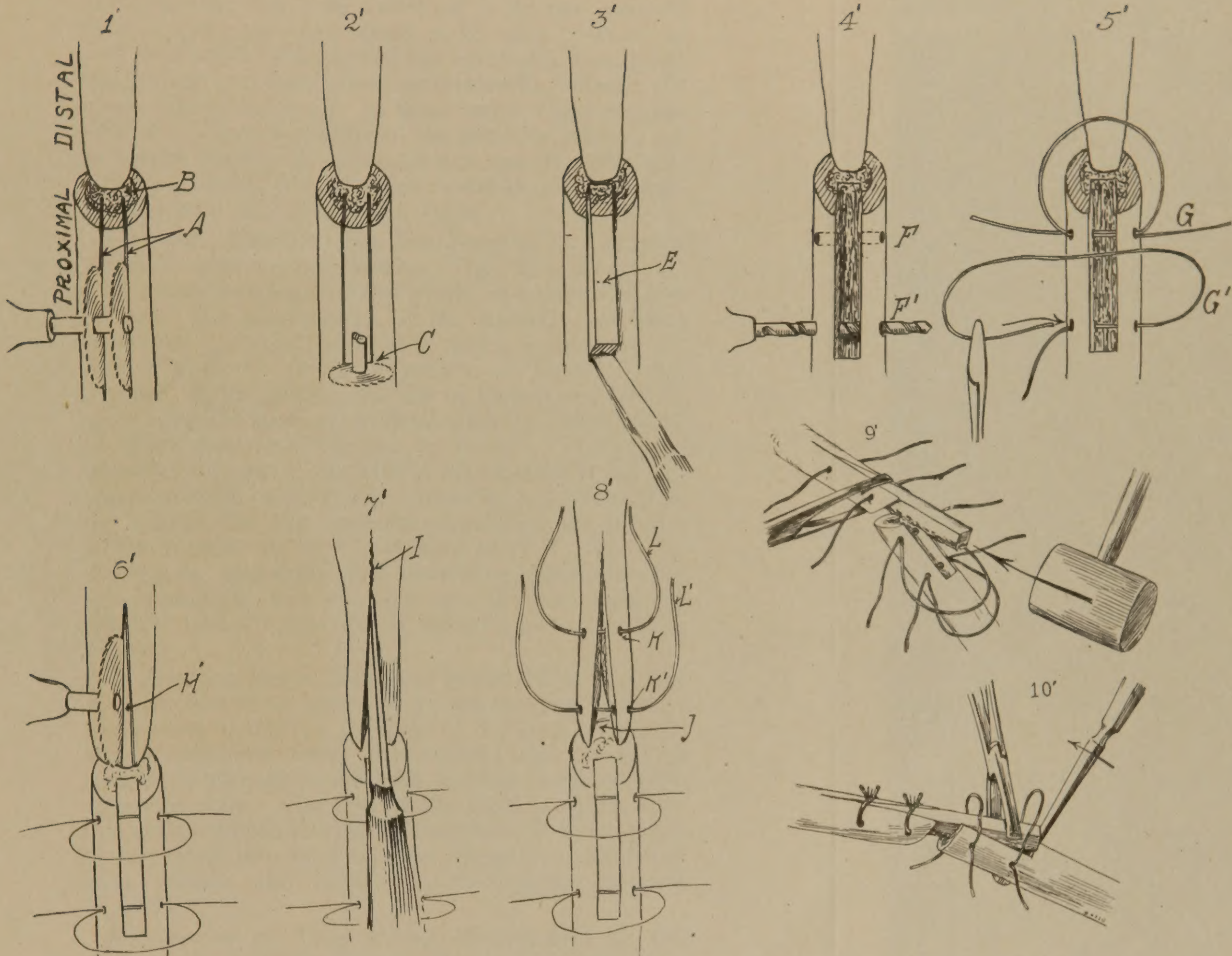

Fig. 6 (Case 4).—Diagrammatic drawings 1′ to 10′ illustrate the author's technic in cases in which the end of the bone fragment (distal or upper fragment in this case) is conical in shape and too small in diameter to receive the usual inlay graft which is shown in the proximal, or lower, fragment in these drawings. A wedge-shaped piece of cortex, *H*, is removed from the upper fragment. A split at the end of the wedge cavity may, or may not, be made by means of a thin osteotome, as shown at *I*. If the fragment is small in diameter and osteoporotic, as is usual in these cases, the bone may be bent on both sides of the cavity in the region of *I*, and the wedge cavity may be enlarged by driving a wedge-ended graft of larger diameter into it, as demonstrated in Step 9′. In Step 10′, the wedge end of the graft is firmly immobilized in the distal or upper fragment by means of kangaroo tendon. The other end of the graft is then forced into the proximal fragment by means of a strong clamp at the same time that the graft is being levered endwise by means of a narrow osteotome, the object of this procedure being twofold; first, to restore as far as possible the length of the ulna, and secondly, to bring end stress on the graft as a stimulus to bone growth. These drawings were made with the distal fragment of the ulna uppermost because of the position of the arm during operation.

end of the fibula to replace the upper portion of the humerus that has been destroyed. He has resorted to this operation many times in his civil practice, as well as in military work, and has invariably found that the patient can functionate satisfactorily without the upper end of the fibula. In these cases, whenever possible, the principal muscles of the shoulder, such as the pectoralis major, the supraspinatus and the subscapularis, are firmly affixed subperiosteally to the transplanted head and neck of the fibula.

Group 2. Shoulder Function Restored by Compensatory Scapulothoracic Motion (Figs. 2, 3, 4 and 5): This group includes cases in which, in addition to loss of bone, the musculature of the shoulder has been destroyed or severely injured to such a degree that one cannot hope to secure a return of shoulder-joint motion. In these cases, the loss of bone is restored by ankylosing the humerus to the scapula by a truss-work of tibial grafts, usually two in number. During the union of the grafts, the arm is immobilized in an elevated anterior posture, and is held in such relation to the scapula that the powerful scapulothoracic muscles which control this bone may later move it. Thus, by causing the scapulothoracic motion to compensate for loss of shoulder motion of the arm, the lost motion of the arm and the shoulder is restored to a surprising degree.

In restoring loss of bone near joints, this technic has been employed: By means of an osteotome or chisel, a wedge-shaped mortise is made in the joint fragment and is extended under the capsule, and sometimes completely through to the joint cartilage, without damaging the joint. One end of the graft is driven into this wedge-shaped mortise. The other end of the graft is then inlaid into the long bone fragment by the usual inlay technic and is fixed with kangaroo tendon (Fig. 3).

Restoration of Long Bones.—Restoration of the shaft of the humerus, femur, tibia or any long, large bone has been accomplished by means of a graft inlaid by the author's usual inlay technic, as illustrated in Figure 6, in the larger fragment at *A, B, C* and *E*. On bones of the forearm, or on any bone of small diameter, or in cases in which a bone of large diameter has become conical-ended, as frequently occurs, the

mode of repair which has been resorted to is designated, for purpose of description, as the "fishpole" technic (Fig. 6 *H*, *I* and *J*), since a similar method is employed by the artisan in mending a fishpole.

The influence of stress on the hypertrophy and metabolism of bone has been more strikingly illustrated in bone graft restoration of the shafts of long bones than in any similar class of work. However small the diameter of the graft, provided it be protected from fracture by external support and at the same time be allowed to withstand stress, it will eventually restore the lost bone in almost every anatomic particular, namely, in diameter, strength and external contour, as well as in respect to the internal architecture.

Immobilization in Extremity Work.—By making

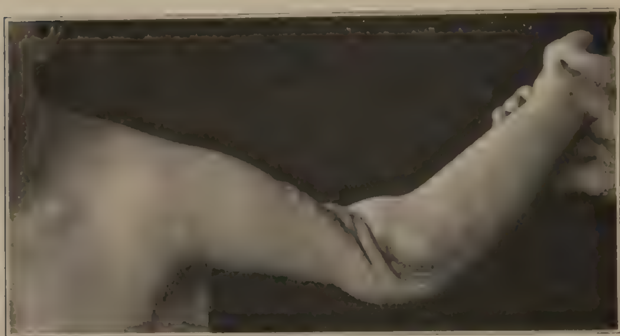

Fig. 7 (Case 2).—Extreme laxity of left arm due to loss of substance in shaft of humerus as result of wound by machine-gun bullet at Cantigny. The plastic operation for restoration of bone and function in this case was performed seven months after injury and two months after wound had healed.

the most of all known mechanical joints and by the insertion of kangaroo tendon in such ways as to afford the best internal fixation, in conjunction with the most perfect external fixation by plaster-of-Paris dressings, the extremity being placed in various "positions of neutral muscle-pull," immobilization of the involved fragments has been found possible. Too great emphasis cannot be laid on the importance of putting absorbable ligatures in the skin, so that carefully applied plaster-of-Paris dressings need not be disturbed for a period of at least eight weeks after implantation of the graft. Plain catgut No. 0 or No. 1 with suture-holes puddled

with tincture of iodin, serves admirably for this purpose. Chromic catgut, No. 0 or No. 1, is also suitable. The buried sutures in the soft parts should always be small in diameter and as limited in number as possible. The only adequate postoperative dressing in these cases is the plaster-of-Paris splint, applied with the utmost care and molded to the bony contours of the extremity. It should always include at least one joint above and one joint below the bone involved, with due

Fig. 8 (Case 2).—Loss of about 1½ inches of shaft of humerus.

attention given to position, which is of the greatest importance. By way of illustration, in cases of injury of the upper portion of the ulna, the arm should always be put up straight, never with the elbow flexed. In cases of injury at or near the lesser trochanter of the femur, the extremity should always be immobilized in a plaster spica with the thigh abducted and flexed.

Synthetic Grafting of Tissues in Construction of New Fingers.—In two cases of loss of four fingers

with the adjoining metacarpal bones as a result of high explosive shell and shrapnel wounds, the hands were completely helpless, so far as grasping and holding were concerned. In these cases, function has been restored to a great extent by the synthetic construction of new digits. One of these cases is illustrated in Figures 12, 13 and 14. By providing an apposing surface for the thumb, the usefulness of the member has in each instance been restored.

Fig. 9 (Case 2).—Method of immobilization of fractures of humerus. In this case the dressing was allowed to remain on for eight weeks.

In plastic work of this nature, which involves the transplantation of more than one kind of tissue, a two-step or multiple-step procedure is the only method whereby a successful sequence may be expected. It is essential, for example, in handling soft parts and bone (as in the construction of new fingers, in plastic repair of the jaw, etc.) that skin and subcutaneous tissues be firmly united with the host-tissue and that circulation therewith be well established before implantation of

bone. Ease of technic and the possibility of obtaining ample soft tissues and bone have also led the author to recommend strongly this type of operative procedure.

Repair of the Mandible.—Probably no branch of surgical repair presents greater difficulty of mechanical fitting and adjusting than in injury to the lower jaw, involving extensive loss of bone. Owing to the irregu-

Fig. 10 (Case 2).—Tibial bone graft firmly united in position, ten weeks after plastic operation.

larity of contour of the jaw fragments, hardness of the bone and lack of anvil stability, such work demands an accuracy and precision of technic that can be secured only by the use of delicately adjusted motor tools, such as the author's tiny circular saws, burrs, drills, end-mills and the like.

Of primary importance is the cosmetic result. In many cases this depends entirely on the construction of a suitable graft framework over which to restore

the contours of the face. Such a framework must secure the adequate fixation of the jaw fragments, as well as restoring, in many instances, loss of bone substance. In his plastic work on the jaw, the surgeon will do well to cooperate, so far as possible, with the prosthetic dentist in the application of the most efficient intradental splints. Use of such splints is, however, in many instances, impossible, owing to the extensive loss of teeth and of bone. In the latter cases, the sole means of fixation must be provided by the graft, which should be molded and firmly inlaid into each fragment, adequate in any emergency (such as removal of the dental splint on account of pressure necrosis, etc.) to supply the requisite fixation.

In other work, such as the restoration of the shafts of long bones, neck of femur, etc., the tibia has been found a satisfactory source from which to obtain the graft. In work on the jaw involving extensive bone loss, however, the tibial dimensions are not always sufficient to supply a graft of the necessary curve and size. In such an event, the side of the ilium, adjacent to the anterior superior spine, is the only bone, with the possible exception of the outer table of the skull, which is of adequate dimension to allow the proper modeling of the graft, which is done by means of motor-driven tools in a manner resembling the scroll-work of the cabinet-maker.

Relief of Compression Fractures of the Vertebrae.—The use of the bone graft as a means for relief of compression fractures of the vertebral bodies has afforded highly satisfactory results. On account of meager bone growth and inadequate bone repair around crushed vertebral bodies, and because of constant interference with bony union by the respiratory and voluntary motion, nature, unassisted, does not bring about the proper repair in these cases, even though efficient external means of immobilization be employed for months, and sometimes even for years. To supply the deficiency resulting from lack of bone repair, the bone graft offers a sure means of relief, and its indications in such cases are as definite as in any pathologic or traumatic conditions encountered. It is inserted into the spinous processes by precisely the same technic as has been devised by the author for the treatment of Pott's disease of the spine (Fig. 15).

Preoperative Treatment of Persistent Infection.—In our first series of 100 fracture cases treated by bone graft, we found that postoperative wound infections were more frequent in the last twenty-five cases than previously. However, these cases did not include in all instances those wounded at a later date, but rather those in which the primary wound took longer to heal; and the later infections, following the plastic operations, are attributed to a more severe primary infection and to a less complete immunization on the part of the patient.

Fig. 11 (Case 2).—Stability of arm from union of graft, ten weeks after operation. Such a posture was impossible before operation.

At the time of the plastic operation, positive cultures were occasionally found in the scar tissue around the bone ends, and small sequestrums were removed from the bone fragments. Not all of these cases, however, showed infection following the operation. In those cases which did, the infection was usually of a mild, low-grade type, apparently owing to the attenuation of the infecting organism or to a partial previous immunization of the patient against that organism.

The scar, on account of its low-grade tissue and its deficient blood supply, furnishes a most unfavorable environment for the reception and nourishment of the graft. To obviate the possibility of subsequent infection in cases which, from their past history, seem unfavorable, and in order to furnish healthy tissues in which to implant the bone graft later, it has been the author's practice to excise the scar at a preliminary operation, laying bare the bone ends, and replacing the scar by plastic flaps of healthy skin, subcutaneous tissue, muscle, fat, etc. If, as has usually been the case,

Fig. 12 (Case 3).—Left hand of an American soldier who lost completely the four fingers and adjoining metacarpal surface following a high explosive shell wound at Château-Thierry. One may note the absence of any apposing surface when the thumb is flexed, as a result of which nothing can be grasped or held.

satisfactory healing of the wound takes place, the bone graft operation follows after a period of from ten days to two weeks. By means of such a two-step operative procedure, healthy tissue is provided for the subsequent implantation of bone, and a successful sequence is more reasonably certain.

Source of Graft Material.—Owing to its accessibility and favorable contour, the tibia, perhaps of all the bones of the body, as a source of graft material affords

the greatest ease of technic. Moreover, bone from the tibia is nearly always preferable for grafting purposes, not only on account of the dimensions and the plane surface of this bone, which permit of a wide choice in the selection of material, but also because of its characteristic strength and osteogenic activity. In the treatment by bone graft of the foregoing series of 100 cases of fracture, the tibia with few exceptions furnished the graft material. The exceptions were in cases of sliding grafts to restore loss of substance in the humerus, femur or tibia, and in one instance of synthetic transplantation of tissues to form a new finger, in which case bone was transplanted from the clavicle.

Avoidance of Operative Trauma.—There are traumatic influences which have an important bearing on the success of a bone graft operation. It is necessary to avoid certain faults in technic, such as excessive

TABLE 2.—SUMMARY OF TIME REQUIRED IN BONE GRAFT OPERATIONS, ACCORDING TO SITE OF INJURY

	Time of Operation	
Bone	Average	Shortest
Humerus	1 hour	45 minutes
Radius	47 minutes	25 minutes
Ulna	33 minutes	19 minutes
Femur	55 minutes	21 minutes
Tibia	23 minutes	14 minutes

length of operating time, with the resultant drying of the graft or host tissues from contact with the air, rough use of the retractors, poor mechanical fit of graft, absence of coaptation of similar bone layers, or direct trauma from wedging or crushing by the chisel and mallet.

Table 2 permits a comparison of the average operating time with the shortest in certain cases, and has been inserted because it is believed that in no other class of surgery does length of operating time so materially influence results. In this work, in which we are dealing with rigid tissues, every effort must be made to maintain to the fullest possible extent the viability of the transplanted bone, a condition largely dependent on the early union of graft tissue with host tissue and on the adequate establishment of nourishment. Drying of the tissues from contact with the air should be con-

Fig. 13 (Case 3).—To restore lost function of hand, the synthetic transplantation of soft tissues and bone was undertaken in a two-step operative procedure. Skin and soft parts were first turned up from the chest wall to form a boneless finger. Through a pedicle left attached to the chest wall, supply of blood was furnished until circulation with the hand was thoroughly established. The hand and arm were immobilized in plaster for four weeks. In the second operative step, the boneless finger was first cut loose from the chest wall. A tibial graft, inserted through the soft parts, was then mortised firmly into the os magnum. A sliver graft, indicated by the arrow, was affixed alongside for increased osteogenesis. The roentgenogram was taken four weeks after the implantation of the grafts, which now have become firmly united to the bones of the hand.

stantly guarded against, not only by the use of saline solution, but by completing the operation in the shortest possible time consistent with good work and with minimum trauma.

Final Results in Forty-Eight Cases.—Too short a time has elapsed to pass judgment, at the present date, on the entire series of 100 cases of fracture. However, in forty-eight cases that were treated before March 1, 1919, and have, therefore, afforded opportunity for observation over a period of at least ten months, we feel justified in reporting definite conclusions.

Of these forty-eight cases, the results in six are questionable; the grafts are still in situ and the roentgen ray reveals bone growth, but the wounds were primarily infected and there yet remain one or more sinuses. Three of these questionable cases, however, show favorable indications of ultimate good results; the other three cases will probably be failures.

Four of the forty-eight cases are definite failures. Of these, one case, a sliding inlay from a tibia to a femur to stabilize a resected knee, was complicated by pneumonia five weeks after the operation; sinuses broke out on both sides of the knee, with a resulting infection of the entire scar tissue of the knee and a failure of part of the graft to "take." Of two radius cases that were failures, one showed a positive Wassermann after, but not before, the operation; and the patient himself removed the fixation dressing on three different occasions. The other radius case showed a bad infection of dense scar tissue. The fourth, and last case of failure, was a humerus case with loss of three inches of substance, and with much scar tissue. The wound broke down, and examination by roentgen ray revealed that the lower end of the graft was not attached to the distal end of the humerus.

Subtracting this group of ten cases, of which four are definite failures and six questionable cases, we have thirty-eight cases remaining, all of which have shown perfect results in respect to postoperative primary healing of the wound, proliferation of new bone as demonstrated by the roentgen ray, and restoration of function. This yields a rate of 79 per cent. perfect results, with a possibility of an ultimate 85 per cent., should three of the questionable cases prove successful.

A complete report of all the plastic operations performed at U. S. Army General Hospital No. 3 will be published as soon as sufficient time has elapsed to permit of trustworthy deductions.

SUMMARY

The following conclusions are based not only on a study of cases and results at U. S. Army General Hospital No. 3, at Colonia, N. J., but also on the author's previous experience with over 1,800 cases treated by bone graft in civilian practice, as well as in extensive

Fig. 14 (Case 3).—New finger six weeks after last operation. The patient is now able to grasp and hold objects with his thumb and grafted finger.

animal experimentation. It is believed that the careful observance of these points is essential to success in this class of work.

1. *Early Observation of Wound.*—A careful study of the wound should be made before it has healed, if possible. The type of infecting organism (*Streptococcus hemolyticus*, gas bacillus, etc.), the nature of the clean-up operation and the manner of healing of the wound should be noted.

2. *Time to Operate.*—In a few cases it is permissible to operate after the wound has been completely healed for a period of two months, while in others, on account

of possible latent infection, it may be advisable to delay the final plastic work for at least six months. In some of the unfavorable latter cases, a two-step operative method may be followed, consisting of a preliminary excision of scar tissue with replacement by a

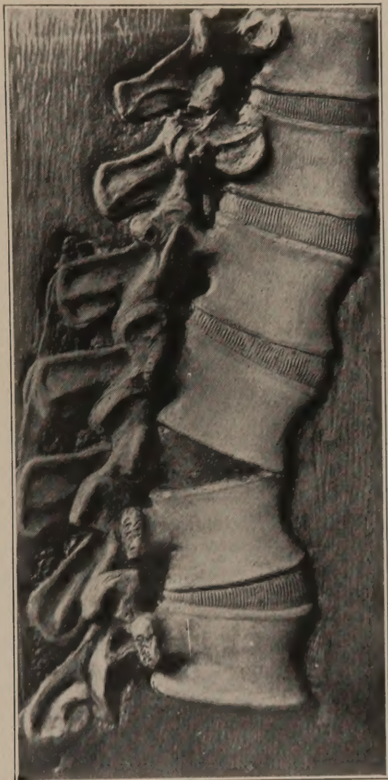

Fig. 15 (Case 4).—Case of compression fracture of third, fourth and fifth lumbar vertebrae caused by fall in dugout. Panel of vertebrae (from clay model of case), showing relief of condition by a tibial graft inlaid into spinous processes from first lumbar to first sacral vertebrae.

healthy skin flap, muscle, fat, etc., followed after a period of from ten days to two weeks by the final bone plastic operation.

3. *Immediate Preoperative Observations.*—For the purpose of determining the existence of latent infec-

tion, splints should be removed, and deep massage and rough manipulation should be practiced for a period of from one to two weeks prior to the operation. During this time the temperature should be observed, and the parts should be carefully examined for local tenderness or any evidence of a recrudescence of infection. The field of operation should have a forty-eight hour preparation, iodin technic being preferred.

4. *Plan of Operation and Choice of Incision.*—By means of roentgenographic and physical examinations, the proposed plan of operation, especially in respect to location of graft, should be determined before incision is made. If possible, the skin incision should not lie directly over the proposed bed of the graft, and the operation should be so planned that the graft may be covered without undue tension of skin and, if possible, so placed that it comes in contact with healthy tissue instead of scar tissue. In several cases in which this has been accomplished, the graft has healed in by primary union, whereas the scar, even at a considerable distance from the graft, has broken down completely. In cases of extensive loss of bone, the scar tissue may be pushed to one side, in order that the graft may lie in healthy tissue. Drainage wicks of any kind should never be inserted at the time of operation.

5. *Duration of Operation.*—It is believed that the shortest possible operating time consistent with good work and with a minimum amount of trauma is requisite to successful results in these cases.

6. *Use of Motor-Driven Instruments.*—These are essential: (*a*) on account of the necessity for rapid work in order that drying and traumatization of the graft tissues and host tissues may be avoided; (*b*) in order that a cabinet-maker fit may provide for mechanical fixation of parts and for the operation of Roux's law of frictional stimulus to bone growth with a view to an early and adequate establishment of nourishment to the graft; and (*c*) on account of the necessity for the fulfilment of the law of anociassociation. The motor outfit with its various tools to produce automatic fits seems indispensable. The motor-saw, when used by the proper technic, does not heat nor glaze the bone.

7. *Adequate Length of Graft.*—The graft should always, when possible, be of the inlay type, and suffi-

ciently long to extend into each fragment for a distance of at least 2 inches, and always beyond the sclerosed area. The gutter should extend well into the healthy marrow of the host-bone, with which the marrow of the graft should be amply contacted. It is exceedingly important that the bridge of marrow from the marrow canal of one fragment to that of the other should be restored for the transmission of blood vessels, bone cells, etc.

8. *Type of Graft.*—The graft should, if possible, be autogenous, consisting of all the bone layers, namely, periosteum, complete thickness of cortex, endosteum and marrow substance; and it should be so inlaid that the fit is perfect, with exact apposition of corresponding layers of graft tissue to those of the host fragments. Such a contacting fit not only favors the mechanical fixation of the fractured bone and the graft, but also the very potent frictional stimulus to bone growth, emphasized by Roux.

9. *Supplemental Grafts for the Purpose of Osteogenesis.*—Small silver grafts placed alongside the principal fixation graft are most efficacious in supplying additional foci for bone growth.

10. *The Graft as Main Fixative Agent.*—Fixation should always be secured by the graft itself, and not by metal plates or other foreign material, since it is the stimulation from the stress carried by the graft itself that is largely responsible for the healthy metabolism of the graft and for bone growth.

11. *Suture Material.*—The graft should be held in place by a minimum amount of absorbable suture, preferably kangaroo tendon, which is the ideal material for this purpose, in that it is tolerated by tissue, readily absorbable, very strong and reliable. Fine absorbable suture material should be used for the skin and underlying soft parts.

12. *Postoperative Fixation.*—The limb should be firmly immobilized by a plaster-of-Paris cast for a period of from eight to ten weeks following operation, and as long thereafter as the roentgen ray shows it to be necessary. Emphasis should again be placed on the importance of using absorbable skin suture material in order that the plaster dressing need not be disturbed until time for the removal of the splint.

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